

INTEGRITY INVESTIGATION OF GROUND ANCHORS

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ABSTRACT

In Japan, Ground Anchors are used a lot for slope stability in roads.

During the maintenance of ground anchors, anchors requiring detailed further investigation have been evaluated by conducting integrity investigations. The integrity investigations can consist of a prior survey, detailed investigation of the anchor head by investigation of the locking unit arrangement, condition of corrosion protection oil after exposing the anchor head, a lift-off test to confirm anchor residual load, investigation below the bearing plate after removal of the locking unit, performance confirmation test, property test of corrosion protection oil and monitoring of axial force in anchors equipped with a load cell.

The Public Works Research Institute and Japan Anchor Association published "Maintenance Manual for Ground Anchors" as result of the collaborations in 2008.

This paper describes anchor integrity investigation from this.

1. THE NECESSITY OF THE MAINTENANCE

Over 50 years passed since the first anchor was used in Japan, and a great many anchors have been used for stabilizing slopes of road mainly. The execution results of permanent anchors of the past ten years (1996-2005) in Japan are about 24,000 projects, total length of about 15,000 km.

20-25% of anchors in service in Japan were constructed more than 10 years ago. Particularly, the durability such as the deformation / damage and a problem about the function come to be seen in a early anchor which construction and corrosion protection technologies were still under development. In addition, it is predicted that anchors reaching the time of the renewal increase in future.

For these anchors, it is necessary to grasp the state of the anchors by premeditated inspection and integrity investigation, and to perform necessary countermeasures for an anchor having a problem in the integrity. And fixing the system to perform these, and establishing technique is demanded.

The Public Works Research Institute and Japan Anchor Association published "Maintenance Manual for Ground Anchors" in 2008.

A way of thinking about inspection and integrity investigation and countermeasure of the anchors is described in this manual to use anchors in integrity condition for a long term, and to plan every possible life extension countermeasure in the anchors that a long term passed.

2. FLOW OF ANCHOR INTEGRITY INVESTIGATION

Situation of anchors is confirmed in detail and integrity of anchors is evaluated by conducting integrity investigation for anchors judged to require integrity investigation by inspection.

An integrity investigation will comprise a prior survey, detailed investigation of the anchor head, lift-off test, investigation below the bearing plate, performance confirmation test, test of corrosion protection oil, and monitoring. The integrity of the anchor is evaluated from the integrity investigation. However, countermeasures such as repair works or enhancement are considered when any problem is discovered. The flow of the maintenance of ground anchors is shown in figure 1, and the flow of the anchor integrity investigation is shown in figure 2.

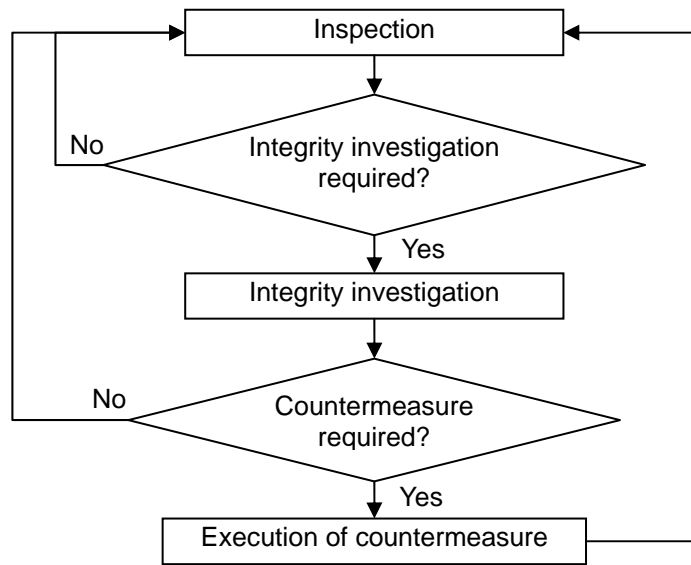


Figure 1. Flow of the maintenance of ground anchor

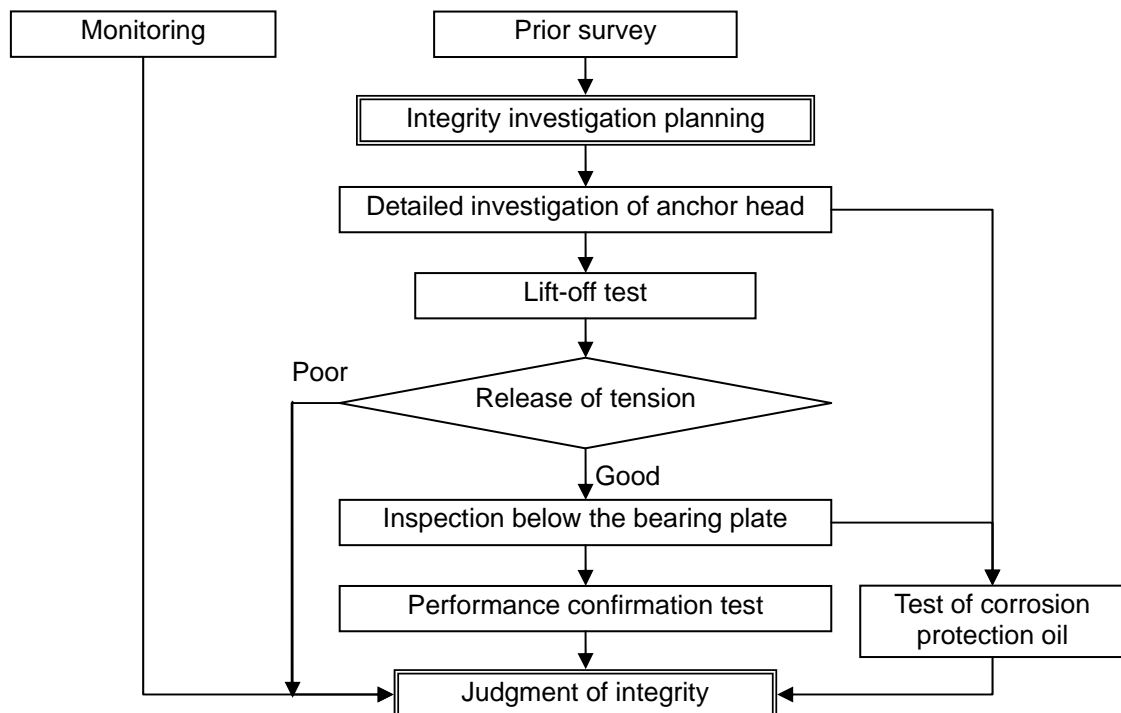


Figure 2. Flow of anchor integrity investigation

3. METHOD OF INTEGRITY INVESTIGATION

Prior survey

Prior survey is conducted to acquire references for judging feasibility of implementation of each investigation and test in integrity investigation. The prior survey includes investigation of published documents, site reconnaissance and Initial preliminary survey.

The investigation of published documents, such as maintenance, management and investigation records, will include examination of specifications, situation and variation of anchors. On the site

reconnaissance, casting position of anchors should be confirmed by inspecting appearance of anchored slopes and anchored structures and comparing received drawings in advance with the situation of sites. Initial preliminary survey also includes a basic visual inspection of the protection to the anchor head and any changes in the anchored structure and variations in the whole structure. Leakage of groundwater is also examined.

Plan of integrity investigation

The type and method of test to be conducted, as well as an investigation into feasibility, are examined from the information collected in the prior survey. An integrity investigation planning sheet designating the implementation plan and operation management in detail is then developed. Safety at the site and its vicinity as well as environmental protection is considered in the plan. The planning sheet will include anchor specification data gained from the prior survey, the type of integrity investigation to be conducted, the location and identification number of the investigation, the method of test and investigation, the equipment and materials to be utilized, method of operation, management and temporary works planning. The number of tests and investigations differ by grade of importance of the anchors being considered and number of anchors installed. The approximate number of tests is estimated based on Table 1.

Table 1. Estimate of number of test and investigations

Type of test and investigation	Estimate of number of tests and investigation	Reference
Detailed investigation of anchor head (Appearance investigation)	Decided by prior survey	Refer to anchor inspection
Detailed investigation of anchor head (Exposure investigation)	Anchor group judged to be required for integrity investigation and 20% from the rest (more than 5 anchors).	
Lift-off test	Anchor group judged to be required for integrity investigation and 10% from the rest (more than 3 anchors).	Confirmation of head part of structure
Investigation below the bearing plate	Anchor group judged to be required for integrity investigation and 5% from the rest (more than 3 anchors).	Possibility of detensioning
Performance confirmation test	All anchors: below the bearing plate investigation	
Test of corrosion protection oil	Area where abnormality is found by visual investigation	Anchor head, below the bearing plate
Monitoring	Anchors equipped with load cell	

Note 1) Anchor group means anchors in the vicinity (up and down, left and right)

Note 2) In case an abnormality is found during the integrity investigation, anchors in the vicinity (up and down, left and right) will also be examined.

Detailed investigation of anchor head

The detailed investigation of the anchor head involves a visual inspection and an investigation after exposure of the head part. The visual inspection will consider variations in the concrete cover (lifting damage, dropping-off, deterioration), variations in the anchor cap (damage, deformation, deterioration), leakage of corrosion protection oil and presence/source of spring water. In the exposure investigation, the anchor cap is removed and the condition of the locking unit, tendon and filling of corrosion protection oil is investigated. The investigation item and content of the detailed investigation for the anchor head are summarized in Table 2.

The result of this investigation is useful for future reference for maintenance and management of the anchor and can be used to diagnose the cause of changes in appearance in the future. The remaining length of the tendon for restressing is then confirmed and reexamination of lift-off test method and judgment of possibility of tension load removal are performed.

After conducting the detailed investigation of the head part, protection to the anchor head is replaced to prevent corrosion of the tendon and locking unit.

Table 2. Investigation item and content of detailed investigation for anchor head

Investigation item	Investigation content	Investigation method	Application
Concrete cover	Lifting, damage, dropping-off, cracking, deterioration	Visual inspection	
Anchor cap	Damage, variation, deterioration, fixing, seal deterioration	Visual inspection	
Corrosion protection oil	Oil leakage, amount, change of quality,	Visual inspection	Performance test of corrosion protection oil
Tendon (remaining length part)	Drawing in, corrosion situation, scratch, damage, remaining length for restressing	Visual inspection, measurement	Measurement of section loss rate
Locking unit	Corrosion situation	Visual inspection	
Bearing plate	Loosening, variation, corrosion, water welled out from the below the bearing plate, deterioration of paint	Visual inspection, hammering sound	



Figure 3. Detailed investigation of anchor head

Lift-off test

The residual load in anchors is confirmed by lift-off test and the anchor integrity is evaluated by comparing this load with the design load and lock-off load. In the test, the remaining length of tendon for restressing is first confirmed and, if necessary, a tool for stressing is manufactured. The loading in the test is simple, and the load and head displacement are measured 10-20kN pitch. The lift-off load (residual load) is determined from the variation point on the load/displacement curve. The apparent anchor free length and abnormality of anchor can be confirmed from the relationship between load and displacement after lift-off. Anchor integrity is confirmed in case that residual load is more than 80% of the lock-off load and less than the design load. Integrity is evaluated as shown in Table 3.

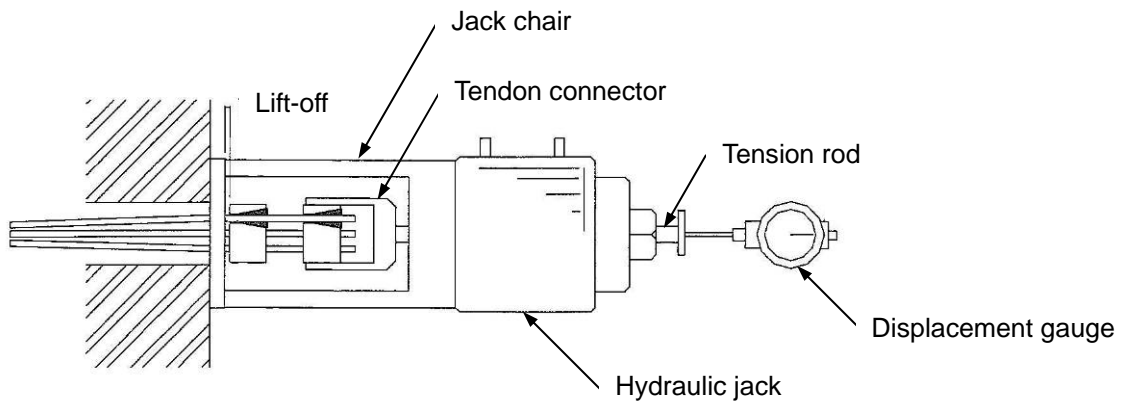


Figure 4. Lift-off test equipment

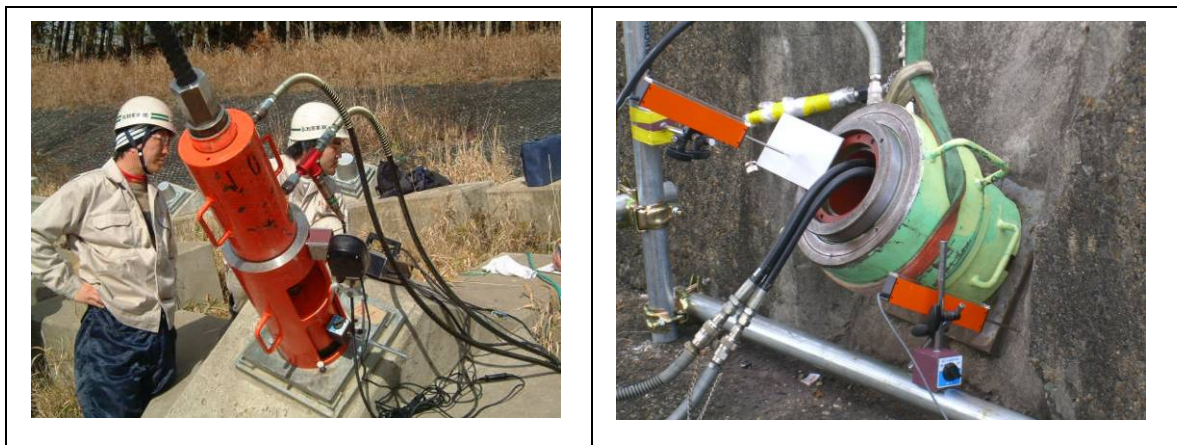


Figure 5. Lift-off test

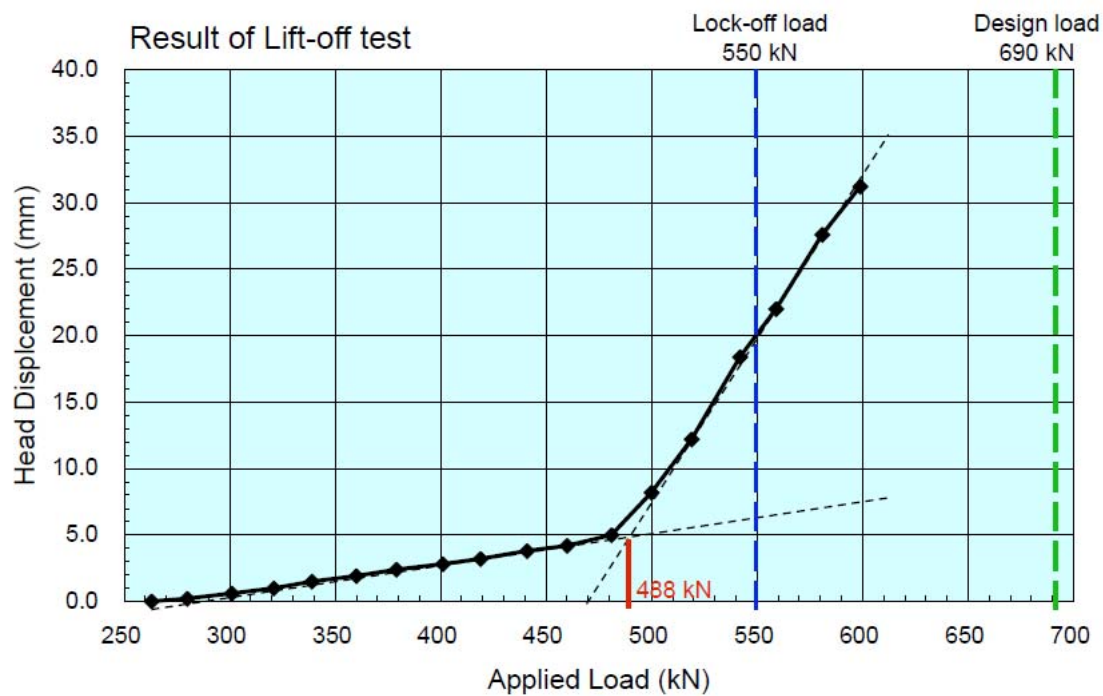


Figure 6. Example of Lift-off test

Table 3. Residual load and anchor integrity

Range of residual load	Integrity	Situation	Countermeasure
0.9Py	E	Possibility to rupture	Emergency countermeasure is necessary.
1.1Ta	D	Possibility of dangerous situation	Countermeasure is necessary.
Allowable load (Ta)	C	Beyond tolerance	
Design load (Td)	B		Necessity of countermeasure is examined by observing process.
Lock-off load (Pt)	A	Sound	
0.8Pt	A	Sound	
0.5Pt	B		Necessity of countermeasure is examined by observing process.
0.1Pt	C	Function is deteriorated drastically.	Countermeasure is necessary.
	D	Non-Functional	

Investigation below the bearing plate

After releasing the anchor load and removing the locking unit an investigation below the bearing plate can conduct. In cases where anchor is fixed by nut, the tensile load is easily released and recovered. But when the anchor is fixed by wedges, it is necessary to confirm the remaining length of the tendon is sufficient for restressing and recovery of the load before the investigation.

During the investigation below the bearing plate, the tendons are examined for corrosion, the filling of the corrosion protection oil is checked and any ingress of groundwater or other variations in condition are reported as detailed in Table 4. As with the anchor head investigation, the results of this investigation can be used as reference for future maintenance and management after examining the cause and phenomenon relating to the observed variations.

Table 4. Investigation item and content of investigation below the bearing plate

Investigation item	Investigation content	Investigation method	Application
Below the bearing plate area	Anticorrosion structure, scratch, water stoppage	Visual inspection	
Tendon	Corrosion, scratch, Damage	Visual inspection	
corrosion protection oil	Oil leakage, amount, changing of quality, deterioration	Visual inspection	Performance test of corrosion protection oil
Infusion of groundwater	Infusion of groundwater, soil	Visual inspection	
Below the bearing plate	Variation, crack, free lime	Visual inspection and measurement	

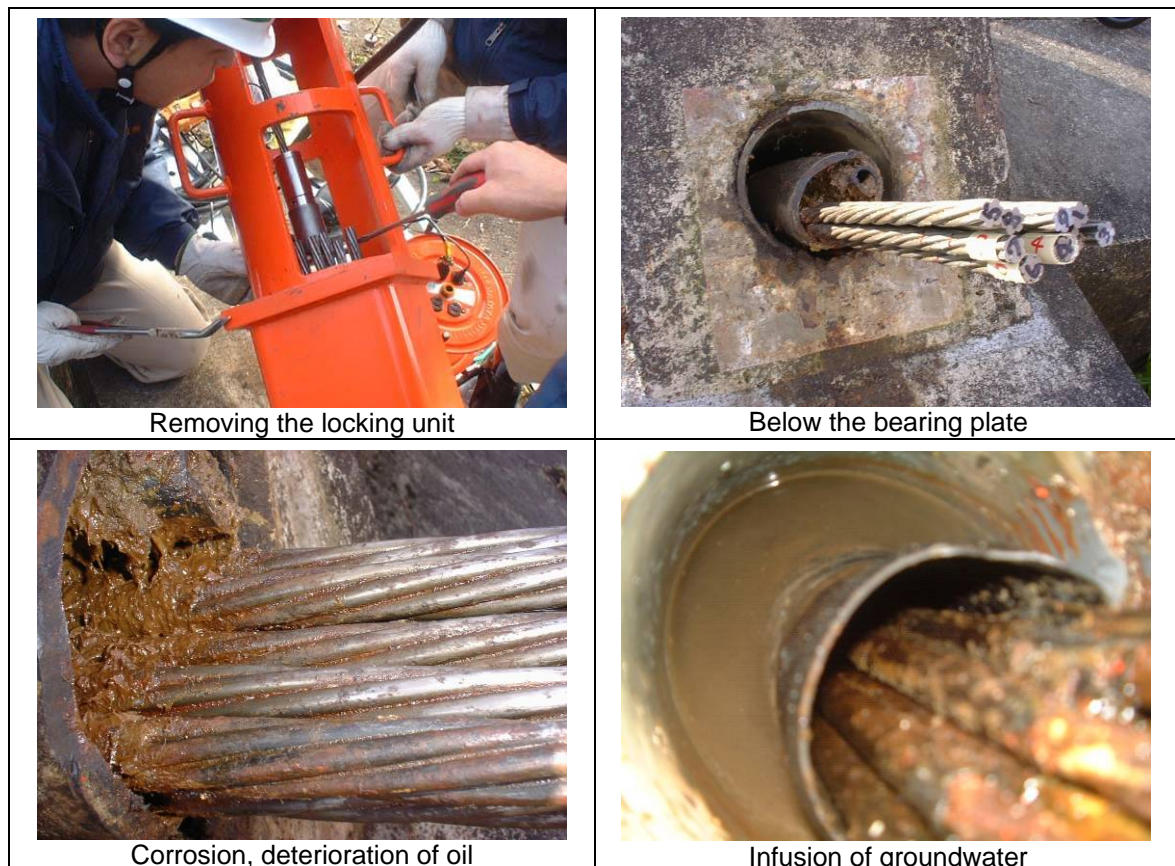


Figure 7. Below the bearing plate investigation

Performance confirmation test

Performance confirmation test confirms the strength of the tendon, the pull-out load of the anchor and the restraining force provided by the anchor are all above the design load. From the test results the anchor can be judged to be effective for future service. Planned maximum load should be within either 1.5 times of usual designed anchor or 1.0 times of designed anchor load at the time of earthquake and also less than 90 % of yield tensile strength of tendon. However, consideration is also given to the results of the detailed investigation of the anchor head and below the bearing plate investigation and the maximum test load reduced accordingly. In the test, loading is applied in cycles of 5 steps until the maximum test load is reached. The apparent free length of the anchor and the factor of safety over the design load for the anchor is confirmed from the relationship between load and displacement, the relationship between load and elastic movement.

Anchor performance confirmation test result

Anchor No.	A-XX
Date	XXXXX
Anchor specification	
Anchor type	XXXXX
Tendon type	$\phi 12.7 \times 8$
Tendon area	789.7 mm ²
Elastic Modulus	192.0 kN/mm ²
Free length	24.0 m
Fixed length	8.0 m
Tendon free length	25.2 m
Design load	800.0 kN
Lock-off load	560.0 kN
Residual load	415.0 kN

Cycle No.	Datum load	Step 1	Step 2	Step 3	Step 4	Step 5
Load (kN)	100.0	240.0	480.0	720.0	960.0	1100.0
Head displacement (mm)	0.0	21.4	59.8	102.9	148.6	180.2
Elastic movement (mm)	0.0	19.8	57.0	98.8	142.7	171.6
Residual movement (mm)	0.0	1.6	2.8	4.1	5.9	8.6
Theory value (mm)	0.0	23.3	63.2	103.0	142.9	166.2
Upper bound value (mm)	0.0	25.6	69.5	113.4	157.2	182.8
Lower bound value (mm)	0.0	20.9	56.8	92.7	128.6	149.6

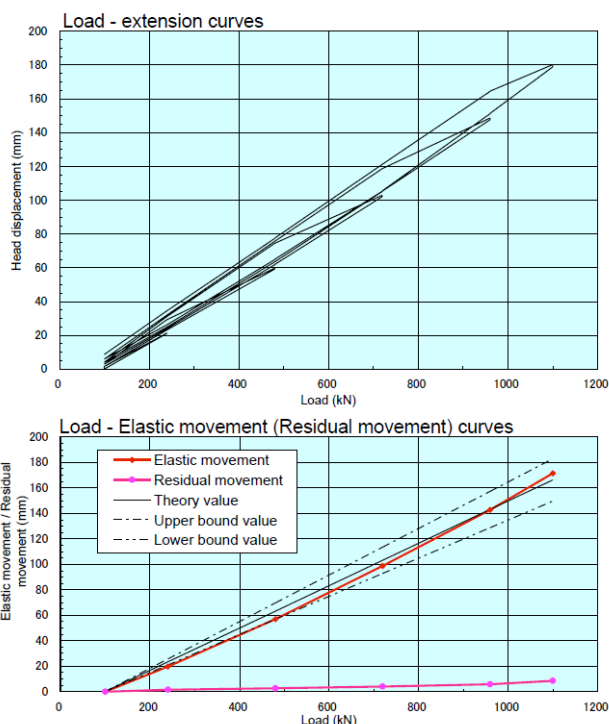


Figure 9. Example of anchor performance confirmation test result

Test of corrosion protection oil

When a change in color of the corrosion protection oil is confirmed by visual inspection during the “detailed investigation of the anchor head” or the “investigation below the bearing plate”, a sample is taken and, if necessary, tested for its corrosion inhibiting property. The property test can be omitted when the number of installed anchors is few and replacement of the compound would be more economical than testing. When deterioration of anticorrosion effectiveness is observed from the test, replacement of corrosion protection oil is necessary.

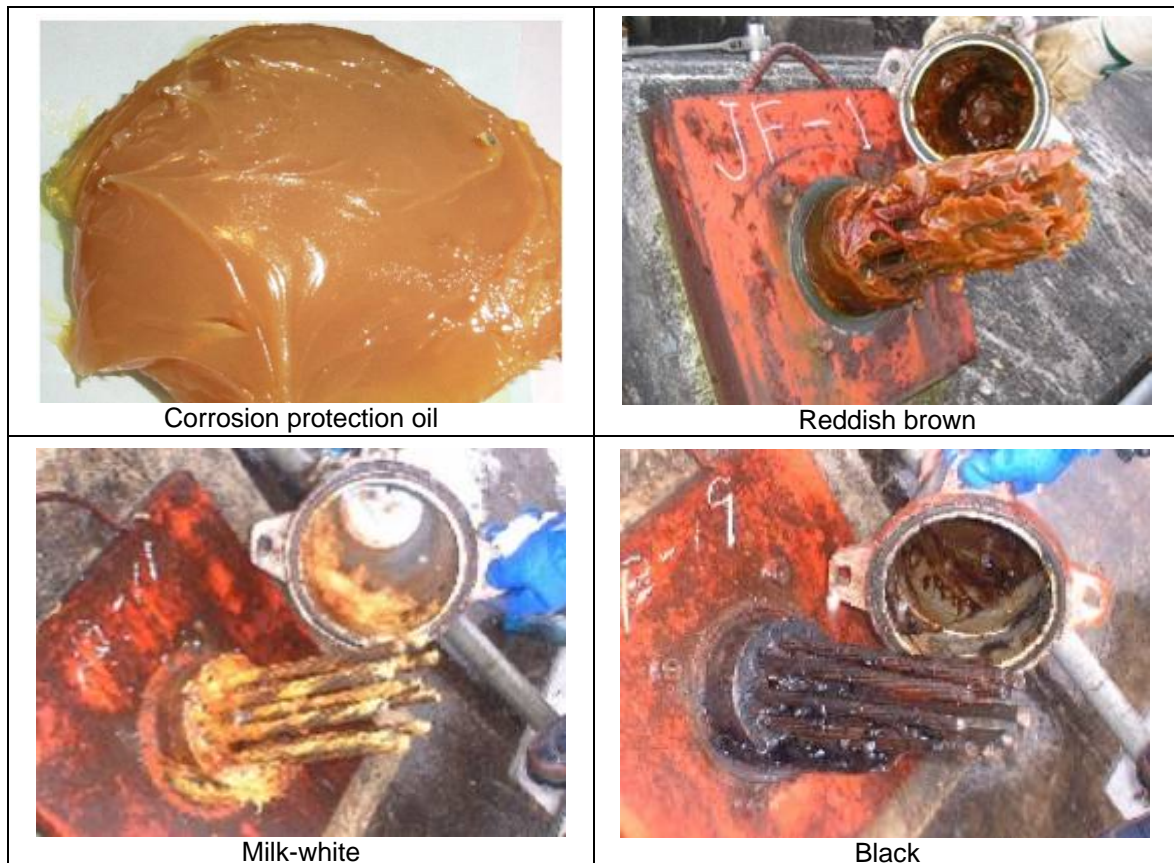


Figure 8. Change in color of corrosion protection oil

Monitoring

A load cell (axial meter) is installed to monitor changes in anchor residual load. By monitoring the axial load, decreases in load as a result of ground creep, increases of earth pressure, changes in the retained slope or increases in load caused by rising groundwater can be measured regularly. The results of monitoring are useful as a reference for judging anchor integrity and estimation of future trends. However, load cells have some implications for the future as they are expensive and have limited durability. Currently, strain gauge load cells, differential transformer load cells and hydraulic disk type measuring instruments are utilized.

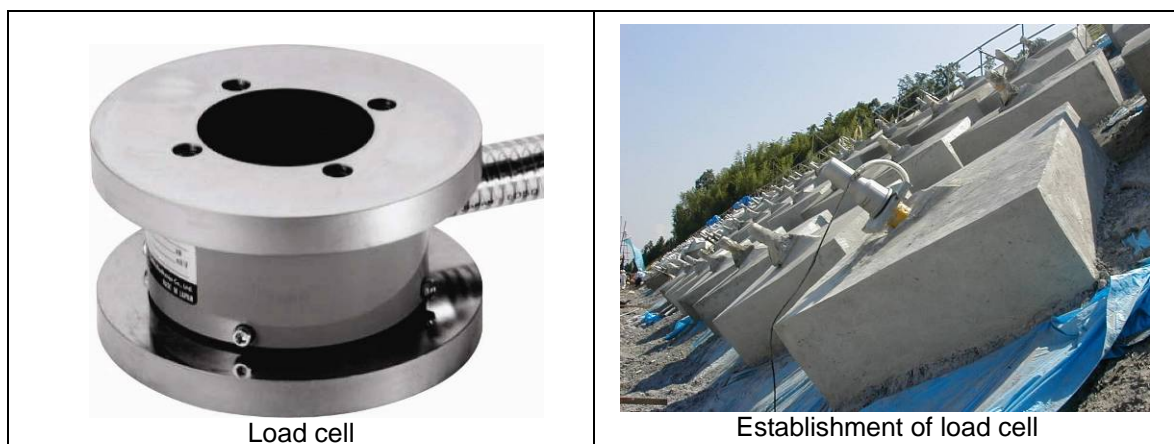


Figure 10. Monitoring

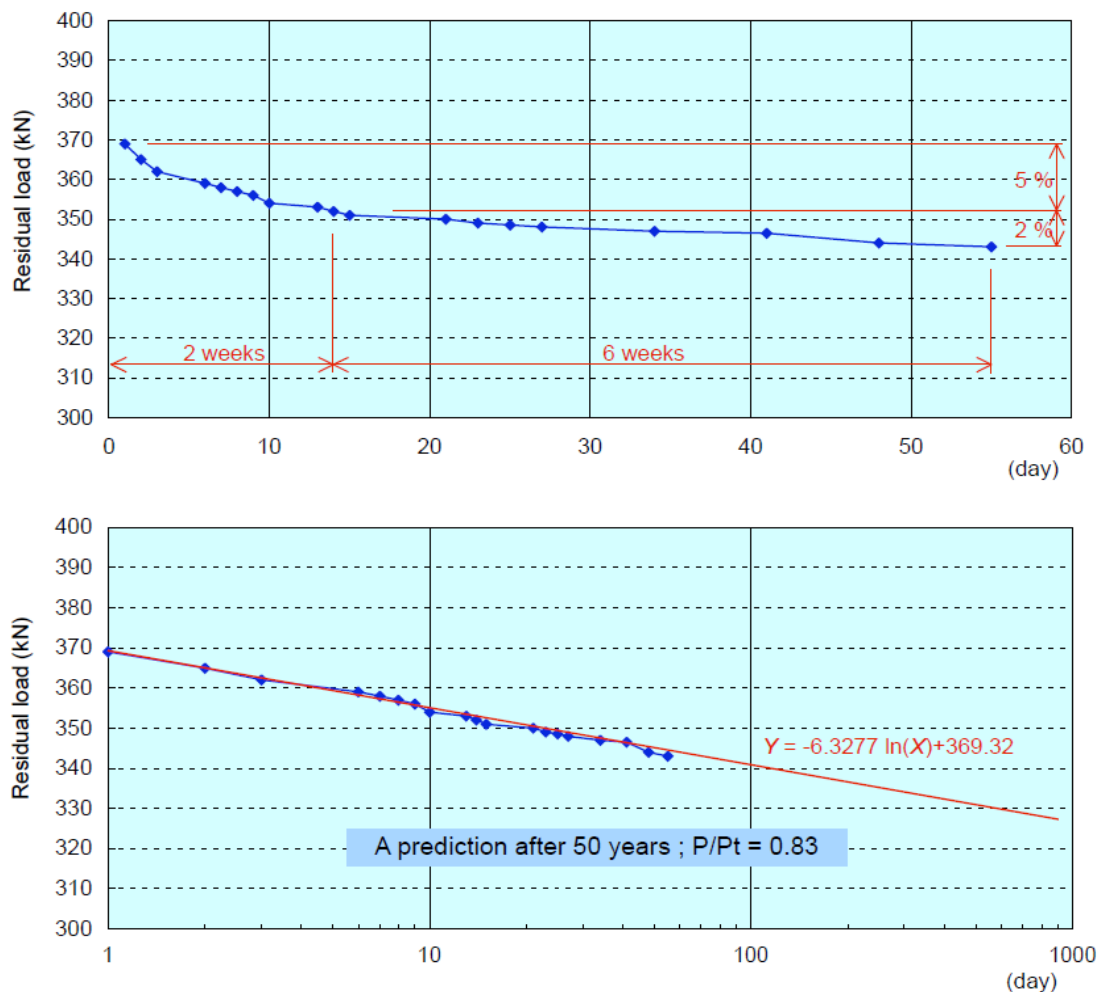


Figure 11. Example of monitoring of residual load

4. Evaluation of investigation result

The integrity of each anchor is clarified from the results of the anchor integrity investigation. Therefore, the integrity of the structure can be evaluated totally from the investigation result. If the investigation concludes that there is a risk of an accident to a third party, urgent countermeasures should be implemented. Possible countermeasures include repairing, enhancement, improvement to durability, life extension countermeasure and renewal.

5. Conclusions

Anchor integrity investigation is a thing to grasp a current condition of anchors, and it is important investigation for doing maintenance. It is big result for the maintenance of anchors that a method of this integrity investigation was made a manual.

The integrity investigation of anchors will be carried out according to "Maintenance manual for Ground Anchors" in future.

References

"Maintenance Manual for Ground Anchors" The Public Works Research Institute and Japan Anchor Association. 2008